III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). These USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by to the USGS to organize and analyze the available data utilize up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of Chatham’s estuaries.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watersheds or contributing areas to the five Chatham estuaries under evaluation by the Project Team. The five estuarine systems are: Muddy Creek, Bassing Harbor/Ryder Cove/Frost Fish Creek/Crows Pond, Stage Harbor, Sulphur Springs/Bucks Creek, and Taylor’s Pond. The watersheds to each embayment were divided into functional sub-units based upon: (a) defining inputs from contributing areas to each major sub-embayment within each embayment system (for example Oyster Pond in the Stage Harbor System or Ryder Cove in the Bassing Harbor System), (b) defining contributing areas to major aquatic systems which might attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed in order to gauge the potential mass of nitrogen from “new” development, which has not yet reached the receiving estuarine waters. The three-dimensional numerical model employed is also being used to define the contributing areas to public water supply wells on the Monomoy flow cell on Cape Cod. Model assumptions for calibration were matched to surface water inputs and flows from current (2002) and historical stream gage information.

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by the land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the source of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to the stream and the portion of the groundwater system that discharges directly into the estuary as groundwater.

Biological attenuation of nitrogen (natural attenuation) occurs primarily within surface aquatic ecosystems (streams, wetlands, ponds) with little occurring within the main aquifer. The freshwater ponds on Cape Cod also provide important environments for the biological attenuation of nitrogen entering them and therefore also require that their contributing areas be delineated. Fresh ponds are hydrologic features directly connected to the groundwater system, which receive groundwater inflow in upgradient areas and discharge water into the aquifer in downgradient areas. The residence time of water within the ponds is a function of pond volume and inflow/outflow rates.

III.2 MODEL DESCRIPTION

Contributing areas to the Chatham estuaries and local freshwater bodies were delineated using a regional model of the Monomoy flow cell. The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al.*, 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to Chatham's estuaries and also to determine portions of recharged water that may flow through ponds and streams prior to discharging into coastal water bodies.

The Monomoy Flow Model grid consists of 164 rows, 220 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below sea level and have a uniform thickness of 10 ft. The top of layer 8 resides at sea level with layers 1-7 stacked above sea level to a maximum elevation of +70 feet. In regions like the Monomoy Lens in which Chatham resides, water elevations are less than +40 ft and therefore the uppermost layers are inactive. Layer 18 has a thickness of 40 feet and layer 19 extends to 240 feet below sea level. The bottom layer, 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics.

The glacial sediments that comprise the aquifer of the Monomoy flow cell consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward sequence with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. Lithologic data used to determine hydraulic conductivities used in the model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and water-level and streamflow data collected in May 2002.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of about 26 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. Since most of Chatham is unsewered, 85% of the water pumped from wells was modeled as being returned to the ground via on-site septic systems.

III.3 CHATHAM CONTRIBUTORY AREAS

Revised watershed boundaries were determined by the United States Geological Survey (USGS) for each of the five major embayment systems within the Town of Chatham (Muddy Creek, Bassing Harbor/Ryder Cove/Frost Fish Creek/Crows Pond, Stage Harbor, Sulphur

Springs/Bucks Creek, and Taylor's Pond) (Figure III-1). Table III-1 summarizes the percent difference in embayment watershed between watershed delineations utilized in previous Chatham assessments (e.g., Stearns and Wheler, 1999) and the newly delineated watersheds obtained using the USGS Cape Cod Groundwater Model. The overall areas of the watersheds to the majority of the embayment systems generally do not change significantly. However, the watershed areas to Little Mill Pond and Frostfish Creek are significantly reduced (36 and 63%, respectively). Ten-year groundwater time-of-travel areas, and contributing areas to selected "large" ponds within each of the five embayment watersheds were also determined (Ponds: Bassing, Emery, Goose, Lovers, Mill, Newty, Schoolhouse, Stillwater, Trout, White). Contributing areas for fresh ponds were delineated if the pond was larger than 3 model grid cells (400 ft X 400 ft each).

Model outputs of watershed boundaries were "smoothed" to correct for the grid spacing, more accurate characterization of the shoreline, and refinement of the embayment segmentation to more closely match the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the Cape Cod Commission, USGS and the rest of the MEP Technical Team. Overall, 52 sub-watershed areas were delineated relating to the 5 embayment systems within the Town of Chatham. Final watershed boundaries are depicted in Figure III-2 (watershed map). Table III-2 provides the daily discharge volumes for various watersheds as calculated by the groundwater model; these volumes were used to assist in the salinity calibration of the tidal hydrodynamic models.

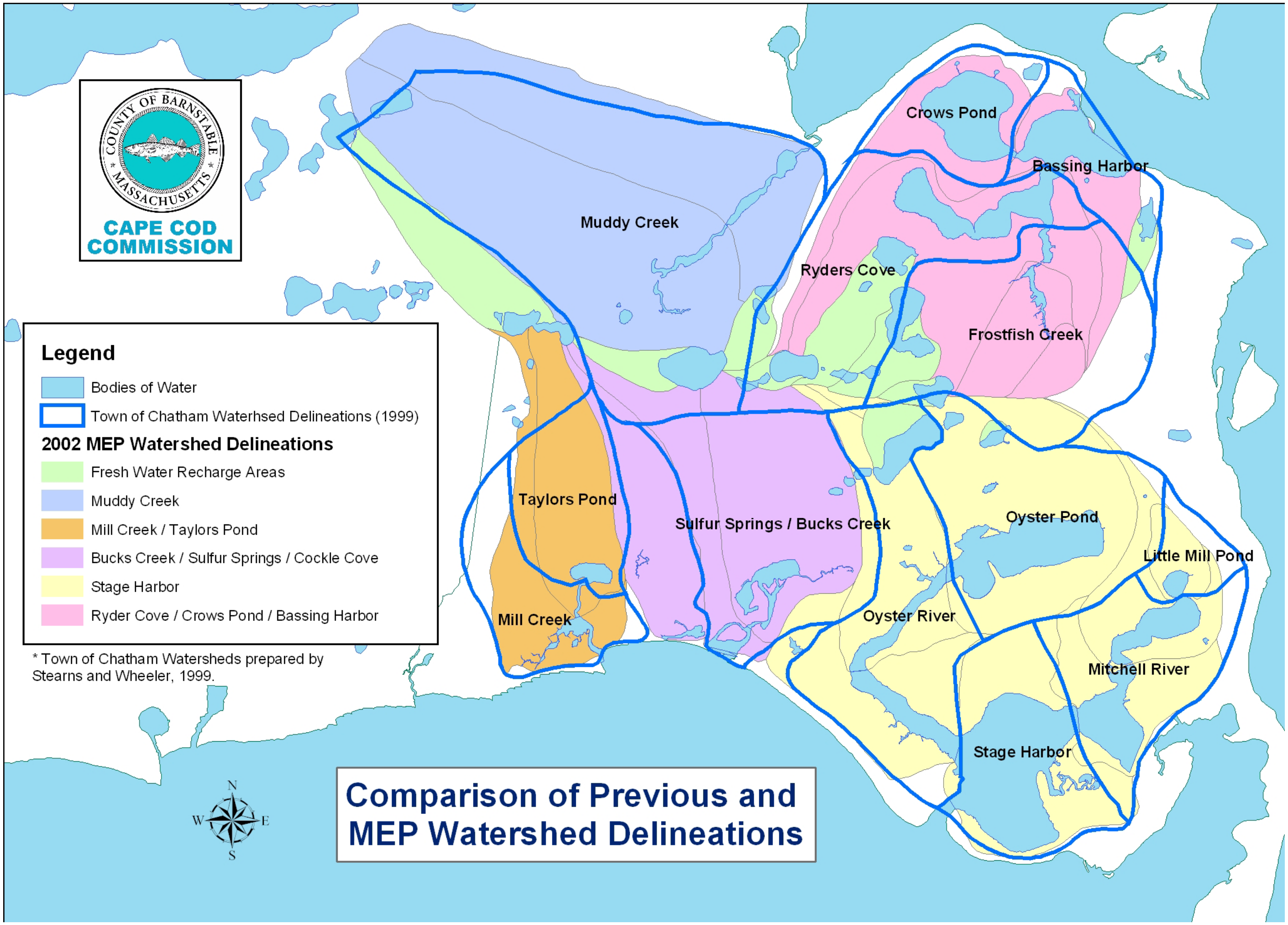

Figure III-1. USGS Cape Cod Groundwater Model revised Town of Chatham embayment watershed delineations

Table III-1. Percent difference in delineated embayment watershed areas between old and newly revised delineations.

Chatham System	*New Watershed (acres)*	*Old Watershed (acres)*	*% Difference*
Muddy Creek System			
Muddy Creek	1871	1855	1%
Stage Harbor System			
Little Mill Pond	83	129	-36%
Mitchell River	521	501	4%
Stage Harbor	554	522	6%
Oyster River	761	772	-1%
Oyster Pond	782	757	3%
Taylor's Pond System			
Taylor's Pond	350	349	0%
Mill Creek	288	340	-15%
Sulfur Springs System			
Sulfur Springs / Bucks Creek	828	793	4%
Basing Harbor System			
Ryders Cove	966	843	15%
Crows Pond	358	306	17%
Frostfish Creek	313	849	-63%
Bassing Harbor	244	287	-15%

Sub-System Name	ID#
Mill Pond Fresh	1
Goose Pond	2
Trout Pond	3
Schoolhouse Pond	4
Stillwater Pond	5
Lovers Lake	6
Emery Pond	7
White Pond	8
Newty Pond	9
Bassing Pond	10
Muddy Creek Well	11
Lower Muddy Creek	12
Lower Muddy Creek 10 E	13
Lower Muddy Creek 10 W	14
Upper Muddy Creek	15
Upper Muddy Creek 10 E	16
Upper Muddy Creek 10 W	17
Mill Creek	18
Mill Creek 10	19
Taylors Pond	20
Taylors Pond 10	21
Cockle Cove	22
Cockle Cove 10	23
Bucks Creek	24
Bucks Creek 10	25
Sulfur Springs	26
Sulfur Springs 10	27
Stage Harbor	28
Stage Harbor 10	29
Lower Oyster River	30
Oyster River	31
Oyster River 10	32
Oyster Pond	33
Oyster Pond 10 S	34
Oyster Pond 10 N	35
Oyster Pond 10 W	36
Mitchell River	37
Mill Pond Salt	38
Mill Pond Salt 10 E	39
Mill Pond Salt 10 W	40
Little Mill Pond	41
Ryders Cove	42
Ryders Cove 10 S	43
Ryders Cove 10 E	44
Ryders Cove 10 W	45
Crows Pond	46
Crows Pond 10	47
Bassing Harbor	48
Bassing Harbor 10	49
Frostfish Creek	50
Frostfish Creek 10	51
Upper Frostfish Creek	52

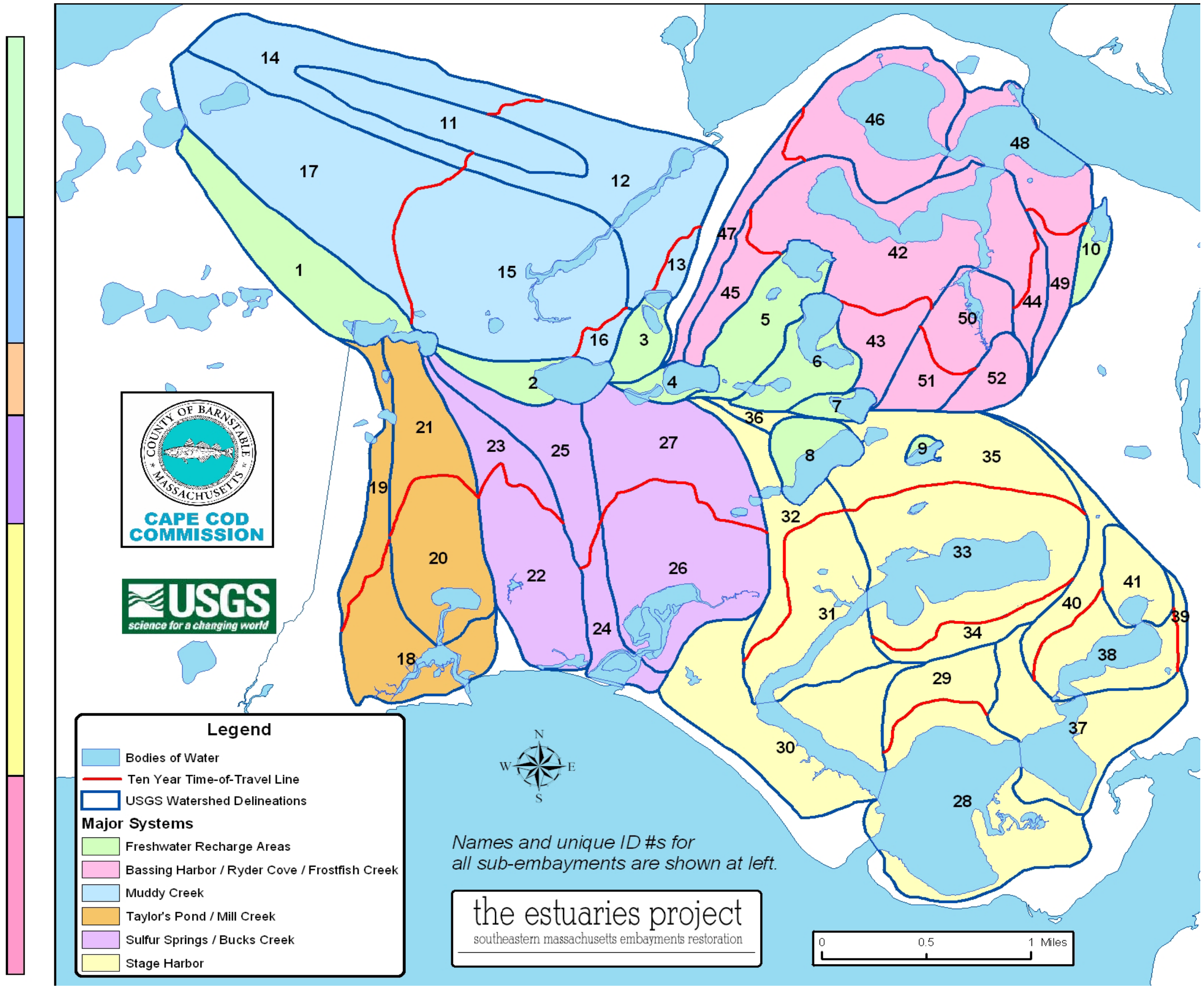

Figure III-2. Watershed and sub-watershed delineations for each of the five major embayment systems within the Town of Chatham, MA. Approximate ten year time-of-travel delineations were produced for quality assurance purposes and are designated with a “10” in the figure legend (left). Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

Table III-2. Daily groundwater discharge to each of the major sub-embayments to the five major embayments within the Town of Chatham, MA, as determined from the groundwater model.

Watershed	Discharge		Watershed	Discharge	
	ft^3/day	m^3/day		ft^3/day	m^3/day
Bassing Harbor	49,835	1411	Mitchell River	24,945	706
Bucks Creek	19,037	539	Muddy Creek	190,410	5392
Cockle Cove Creek	82,466	2335	Oyster Pond	185,580	5255
Crows Pond	71,255	2018	Oyster River	117,080	3315
Frost Fish Creek	47,728	1352	Ryder Cove	191,530	5424
Little Mill Pond	18,710	530	Stage Harbor	44,180	1251
Mill Creek	80,189	2271	Sulphur Springs	127,830	3619
Mill Pond	55,140	1561	Taylor Pond	29,448	834
			Upper Muddy Creek	291,190	8246

III.3.1 Well Pumping Effects: Taylors Pond / Mill Creek Watershed

During the review of the Town of Chatham's Comprehensive Wastewater Management Plan effort, concerns were raised as to the effect of the drinking water withdrawal wells (located northwest of Taylors Pond) on the groundwater flow to the Taylors Pond System. These wells operate seasonally to meet summer water-use demand. The issue of the wells was raised when preliminary nitrogen loading assessments completed prior to the initiation of the MEP had difficulty reconciling observed nitrogen concentrations in the Taylor's Pond with estimates based on watershed land uses (Applied Coastal, *et al*., 2001). During a review (by the Town Wastewater Technical Committee and MEP staff) of information used to develop the watershed nitrogen loads under the town's facility plan (Stearns and Wheler, 1999), it was determined that the impact of pumping from nearby Harwich and seasonal Chatham municipal drinking water supply wells was not considered in the initial assessment. As a result, the Town initiated a further investigation of the effects of the water withdrawals on groundwater flow and contributing area to the Taylors Pond System (Earth Tech 2002).

Given the results of the Earth Tech study which indicated that water withdrawals could be influencing groundwater flow patterns in the region of the Taylors Pond System, the MEP Team undertook further modeling studies. The newly constructed USGS groundwater model was used to address the following questions: (a) to what extent are the Harwich and seasonal Chatham municipal drinking water supply wells altering the watershed boundaries to Taylor's Pond and Mill Creek and (b) are these well withdrawals causing seasonal changes in groundwater discharge rates to the receiving estuarine system.

USGS staff conducted modeling runs based upon the Town's recorded winter and summer pumping extremes. These pumping data were taken from a review of monthly withdrawal records between 1995 and 2000. These monthly extremes were then treated as steady-state conditions in order to evaluate the impact on the Taylor's Pond and Mill Creek watershed delineations. The concept was to constrain the maximum extent of seasonal shift in watershed boundary resulting from seasonal water withdrawal.

The results of the MEP modeling effort were qualitatively consistent with the previous study showing a shift in watershed boundary. However, the MEP study indicated that the shift was small and would have little effect on the nitrogen discharge rate from the watershed to either Taylors Pond or Mill Creek (Figure III-3). Further examination of the results indicated that while well withdrawals produced little effect on nitrogen loading to the Taylors Pond System, the spatial coverage of the MEP watersheds differed significantly from the boundaries used in the earlier nitrogen loading study. Therefore, it appears that the difficulties reconciling the monitoring data with the nitrogen loading estimates in the previous nitrogen modeling studies resulted primarily from the areal coverage of the contributing area rather than a seasonality of withdrawal.

Figure III-3 compares the model watershed outputs from the winter and summer conditions and the average conditions. This comparison shows that the summer pumping of the wells causes a slight movement of the watersheds toward the east, but that the average condition watersheds are appropriate for the subsequent land use and nitrogen loading analysis.

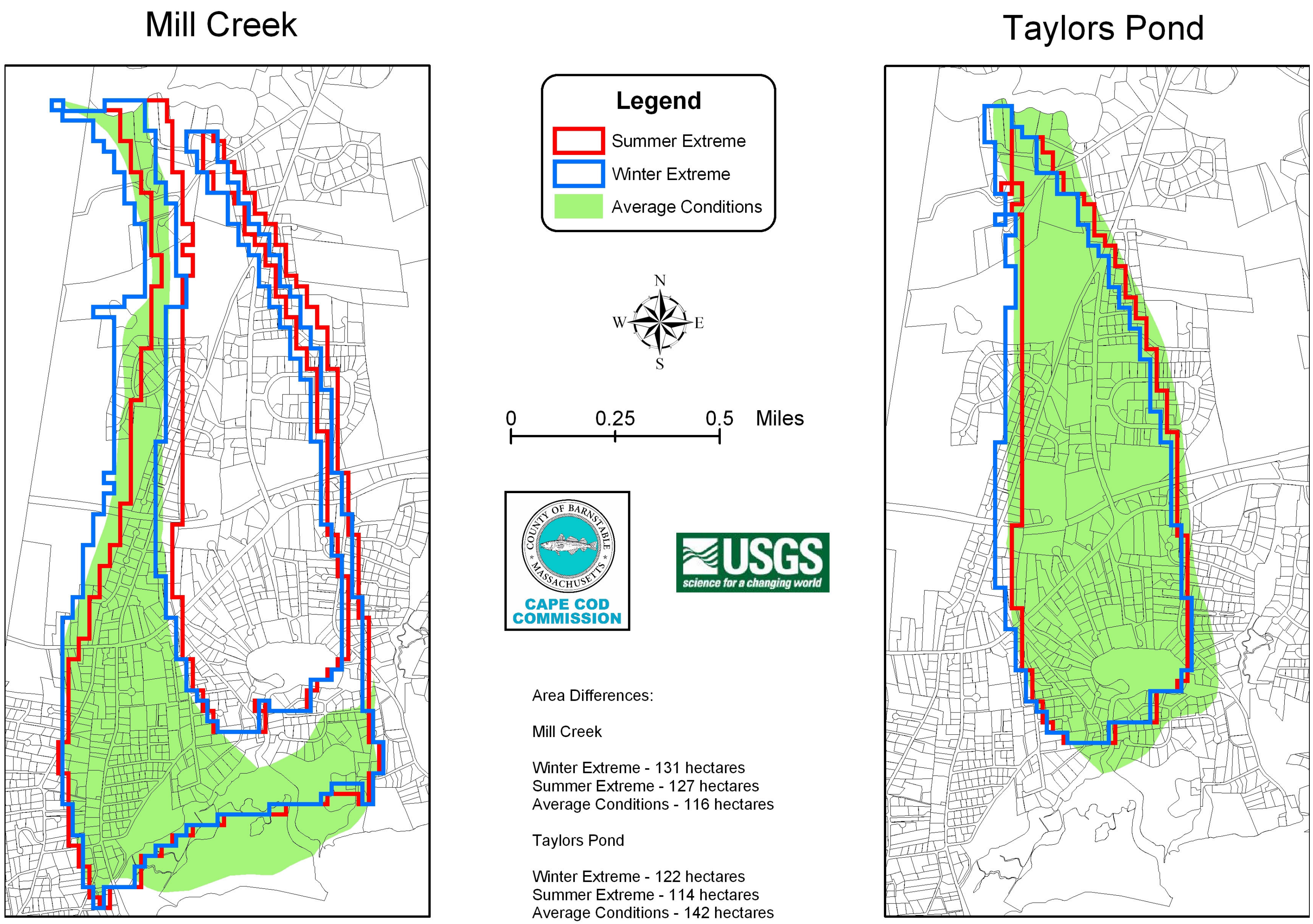

Figure III-3. USGS Cape Cod Model watershed outputs illustrating winter and summer pumping conditions relative to average conditions.